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Injury to Wild Brook Trout by Backpack Electrofishing

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Abstract.—Most studies of salmonid injuries caused by electrofishing have been conducted on adult brown trout *Salmo trutta* and rainbow trout *Oncorhynchus mykiss* in medium- or high-conductivity waters. The objective of this study was to assess internal injuries of wild brook trout *Salvelinus fontinalis* that were captured with AC and pulsed-DC backpack electrofishing units in four small, low-alkalinity streams. We used X rays and autopsies to assess the injury rate of 579 brook trout (95–237 mm total length, TL) captured by electrofishing. Injuries consisted of either internal hemorrhages, spinal misalignment and fracture, or both. We found a total of 74 hemorrhages and 91 spinal injuries. Injury rates of brook trout captured by electrofishing were not significantly different ($P > 0.05$) between electrical wave forms: 26% for AC and 22% for pulsed DC. Injury rate increased with fish length, ranging from 14% for fish smaller than 125 mm TL to 42% for fish 175 mm TL or larger. In spinal-injured fish, damage occurred to an average of six vertebrae, usually ones in the posterior region of the spinal column between the dorsal and anal fins. We also examined 89 brook trout (87–225 mm TL) captured by angling. Less than 7% of the angled fish had injuries, all detected by X ray. We conclude that the incidence of electrofishing-induced injury can be substantial, even for relatively small brook trout in low-alkalinity waters. The relation of these injuries to mortality remains to be explored.

Though electrofishing is an efficient, widely used method of collecting trout from streams, trout exposed to electrofishing may experience behavioral changes (Bouck and Ball 1966; Mesa and Schreck 1989), physiological stress (Bouck and Ball 1966; Schreck et al. 1976; Mesa and Schreck 1989), reduced growth (Gatz et al. 1986), physical injury (Hauck 1949; Hudy 1985; Sharber and Carothers 1988), or death (Pratt 1954; Bouck and Ball 1966; Hudy 1985). Sharber and Carothers (1988) recently refocused concern on the problem of spinal injury to trout due to electrofishing when they reported 50% injury of wild rainbow trout *Oncorhynchus mykiss* in the Colorado River. Most published studies of injury of wild trout have involved large (≥34 cm) rainbow trout or brown trout *Salmo trutta* in large, highly conductive (≥300 μS/cm) streams (Hauck 1949; Sharber and Carothers 1988; Meyer and Miller 1990). Pratt (1954) and Hudy (1985) reported relatively low injury (0–5%) of hatchery-reared brook trout *Salvelinus fontinalis* exposed to electrofishing. We are not aware of any published studies of physical injury to wild brook trout by electrofishing.

Our purpose was to document the type and extent of injuries that resulted from electrofishing wild brook trout in small streams. In Pennsylvania, these streams are usually accessible only by foot, and lightweight backpack electrofishers, which produce alternating current or pulsed direct current, are typically used to capture fish.

Methods

Wild brook trout were electrofished from Gann Run (41°04'27"N, 77°14'03"W) in Clinton County, Pennsylvania, and from Smays Run (40°53'46"N, 78°01'18"W), Little Fishing Creek (40°55'20"N, 77°38'26"W), and Galbraith Gap Run (40°45'46"N, 77°45'07"W) in Centre County; these are typical headwater brook trout streams in the northcentral part of the state. Catchments are covered by second-growth hardwood forest. Study streams are short (2.1–11.1 km long), narrow (3.2–4.6 m wide), and shallow (<50 cm deep); they flow over sand, gravel, and rubble substrate, underlain by sandstones, conglomerates, and shales. Previous sampling had found the study streams typically low in conductivity (28–72 μS/cm) and weakly buffered (total alkalinity, 8–11 mg/L as $CaCO_3$). When we sampled, stream water temperatures varied from 8 to 11°C and specific conductance ranged from 43 to 440 μS/cm (Table 1). Apparently, drought and inflow from a high-conductivity source raised conductivity to an unex-

TABLE 1.—Stream conditions and outputs of AC and pulsed-DC (PDC) electrofishers during collections of wild brook trout in four Pennsylvania streams in 1991.

		Stream conditions		Electrofisher variables		
Stream	Date	Water temperature (°C)	Conductivity (μS/cm)	Current	Volts	Amperes
Gann Run	24 Oct	11.0	440[a]	AC	125	0.75–1.5
				PDC	200	0.5
Smays Run	24 Oct	11.0	64	AC	350	1.0–1.75
				PDC	400	0.25
Little Fishing Creek	25 Oct	10.0	50	AC	350	0.75–1.5
				PDC	500	0.2
Galbraith Gap Run	23 Oct	8.0	43	AC	400	0.75–1.5
				PDC	500	0.2

[a] Abnormally high value apparently caused by inflow from high-conductivity source during low stream flow.

pectedly high level in Gann Run, but circumstances did not allow us to substitute another stream.

Brook trout were captured by angling, AC electrofishing, and pulsed-DC (PDC) electrofishing between 17–25 October 1991. Prior to electrofishing, brook trout were collected by two anglers using artificial flies or live bait. Part of the same reach of each stream was electrofished with AC 2–4 d later, and a separate, adjoining reach was electrofished with PDC. Electrofisher output was adjusted as we normally would for effective fish capture. Each stream was electrofished by two experienced operators, who each wielded an electrode probe in one hand and a dip net in the other. One operator wore the backpack electrofisher while both fished upstream. Brook trout collected by each method were held separately in buckets of water, administered a lethal dose of anesthesia, and then placed on ice for transport to the laboratory, where they were frozen.

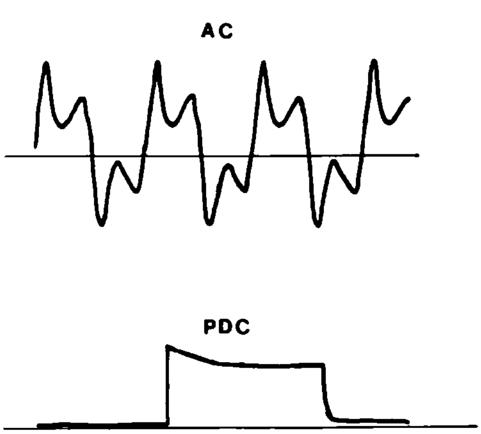

FIGURE 1.—Oscilloscope traces of wave forms of AC and pulsed-DC (PDC) electrofishers while under full load.

Two backpack electrofishers were used: (1) a gasoline-powered generator (Tanaka) with a variable-voltage transformer (Coffelt model BP-1C), which produced AC of 100–700 V and (2) a battery-powered PDC unit (Smith-Root model 12) with 100–1,000-V output. Electrofisher voltage settings and outputs during electrofishing were 125–400 V AC at 250–300 Hz and 0.75–1.75 A, and 200–500 V DC at 60 Hz and 0.2–0.5 A (Table 1). Two rings, each 29 cm in diameter and constructed of stainless steel tubing (6- or 9.5-mm outside diameter) served as electrodes. Electrofisher wave forms were later measured in the laboratory under full load. The AC backpack electrofisher produced a highly modified sine wave; the PDC electrofisher produced a square wave with a fast rise and slow decay (Figure 1).

One to two months after collection, the brook trout were thawed, X-rayed from the left side, and filleted. Any internal injury associated with the spinal column was noted. We defined two types of injury: (1) internal hemorrhage associated with the spine or (2) misalignment of the spine and compression or fracture of vertebrae. The type and severity of each injury was rated according to criteria proposed by J. B. Reynolds (Alaska Cooperative Fish and Wildlife Research Unit, personal communication; Table 2). The fish were X-rayed with Kodak Blue Brand BB-1 film, exposed at 40 kV, 50 mA, for 0.1 s, or Kodak Industrex AX-2 or AA film, at 50 kV, 100 mA, for 1.5 s. Each brook trout was measured for total length (TL, mm), filleted along both sides of the spine, and examined for hemorrhage. If a hemorrhage was detected, its severity was rated, and a 35-mm color slide photograph was taken of the brook trout and the fillet. After autopsy, X-ray photographs were preliminarily inspected to detect and rate com-

TABLE 2.—Injury rating system used to identify and rate the severity of electrofishing injury.

Rating class	Internal hemorrhage	Spinal damage
0	None apparent	None apparent
1	Wounds separate from spine	Compression of vertebrae
2	Wounds on spine ≤ width of 2 vertebrae	Misalignment and compression of vertebrae
3	Wounds on spine > width of 2 vertebrae	Fracture of ≥ 1 vertebrae or complete separation of ≥ 2 vertebrae

pression, misalignment, or fracture of vertebrae. X-ray photographs were reexamined, a final rating of each injury was determined, and the location and number of injured vertebrae recorded. Finally, X-ray photographs were examined by an orthopedic surgeon to confirm the detection and rating. Final rating of hemorrhages was done by reviewing projections of the 35-mm color slides. Ratings of spinal injuries and hemorrhages were not determined entirely independently of each other. We had access to previous ratings, although we did not routinely compare the ratings.

Results

We captured 579 brook trout by electrofishing (281 by AC and 298 by PDC) and 89 by angling (Table 3). Average total length of the fish was 136 mm (range, 87–237 mm; SD, 29.58). One hundred forty (24%) electrofished brook trout had either hemorrhage (53%), spinal injury (65%), or both (18%).

Of all brook trout collected by AC electrofishing, 13% had hemorrhages, 18% had spinal injuries, and 5% had both types of injury (Table 3). Most hemorrhages (61%) were rated as class 2; most spinal injuries (41%) were class 1 and involved an average of 5 vertebrae (range, 2–15). Of all brook trout collected with PDC electrofishing, 13% had hemorrhages, 13% had spinal injuries, and 4% had both. Class-2 hemorrhages were most common (71%); most spinal injuries were classes 2 and 3 (40% each) and involved, on average, 7 vertebrae (range, 2–18). Spinal injuries from both AC and PDC were usually located in the region of the spinal column between the dorsal and anal fins.

Both types of injuries did not always occur together. Among the 281 fish captured with AC, 207 had no hemorrhages or spinal injury, but 38 fish (16%) had a spinal injury but no hemorrhage, and 23 fish (10%) had hemorrhages but no spinal injuries (Table 4). Similarly, among 298 brook trout captured with PDC, 28 fish (11%) had a spinal injury but no hemorrhage, and 26 fish (10%) had a hemorrhage but no spinal injury (Table 4). These results indicate that accurate assessment of injury

TABLE 3.—Incidence of internal injury and classification of injury severity (see Table 2) wild brook trout captured by electrofishing and by angling from four Pennsylvania streams in October 1991.

	Number of brook trout			Hemorrhage rating			Spinal injury rating		
Stream	Uninjured	With both hemorrhage and spinal injury	With either injury type	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
AC electrofishing									
Gann Run	60	3	10	1	3	0	1	7	1
Smays Run	46	5	32	2	6	7	10	7	5
Little Fishing Creek	56	2	9	1	3	1	5	1	0
Galbraith Gap Run	45	3	23	1	10	1	5	2	7
Total	207	13	74	5	22	9	21	17	13
Pulsed-DC electrofishing									
Gann Run	62	1	6	1	1	3	0	2	0
Smays Run	56	6	39	0	15	5	5	9	11
Little Fishing Creek	62	3	10	0	7	0	2	2	2
Galbraith Gap Run	52	2	11	4	1	1	1	3	3
Total	232	12	66	2	27	9	8	16	16
Angling									
Gann Run	44	0	6	0	0	0	4	1	1
Smays Run	10	0	0	0	0	0	0	0	0
Little Fishing Creek	19	0	0	0	0	0	0	0	0
Galbraith Gap Run	10	0	0	0	0	0	0	0	0
Total	83	0	6	0	0	0	4	1	1

TABLE 4.—Combinations of spinal damage and hemorrhages of different severities (or ratings; see Table 2) in wild brook trout captured by electrofishing in streams. Data given are numbers of fish.

Hemorrhage rating class	Spinal damage rating class: 0	1	2	3
	AC electrofishing			
0	207	16	9	13
1	3	1	1	0
2	15	2	5	0
3	5	2	2	0
	Pulsed-DC electrofishing			
0	232	3	10	15
1	1	0	1	0
2	19	5	2	1
3	6	0	3	0

TABLE 5.—Incidence of injured wild brook trout (those with hemorrhage, spinal injury, or both), by length-group, in collections made by electrofishing or angling in streams.

Total length (mm)	Number of brook trout: Total	Injured	Uninjured
	AC electrofishing		
<125	117	19 (16%)	98
125–174	130	41 (32%)	89
≥175	34	14 (41%)	20
All	281	74 (26%)	207
	Pulsed-DC electrofishing		
<125	128	15 (12%)	113
125–174	128	33 (26%)	95
≥175	42	18 (43%)	24
All	298	66 (22%)	232
	Electrofishing (combined data)		
<125	245	34 (14%)	211
125–174	258	74 (29%)	184
≥175	76	32 (42%)	44
All	579	140 (24%)	439
	Angling		
<125	49	3 (6%)	46
125–174	36	3 (8%)	33
≥175	4	0 (0%)	4
All	89	6 (7%)	83

rates should include both autopsy and X-ray examinations.

About 7% of angled brook trout had injuries. All six injured brook trout (range, 119–136 mm TL) were captured in Gann Run. Four brook trout had class-1, one had class-2, and one had class-3 spinal injuries. Two to four vertebrae were injured. No hemorrhages were seen in any angled brook trout (Table 3).

Injury rate was not significantly different between the two electrofisher types (χ^2, $P > 0.05$); therefore, we summed the incidences of injury from both current types and tested for differences among streams. The combined electrofishing injury rates were significantly different (χ^2, $P < 0.05$) among streams: Gann Run, 12%; Little Fishing Creek, 14%; Galbraith Gap Run, 26%; and Smays Run, 41%.

Injury rate increased as the length of the brook trout increased. We arbitrarily grouped the catch of each electrofisher into three length-groups and calculated the total injury rate per group by gear. The injury rate for both AC and PDC was lowest (12–16%) for brook trout smaller than 125 mm TL, was intermediate (26–32%) for the 125–174-mm length-group, and was highest (41–43%) for the 175-mm and longer length-group (Table 5). Injury rate was significantly different among length-groups (χ^2, $P < 0.05$).

Discussion

Because of the difficulties in detecting some internal injuries, it is possible that the injury rate we report may be a conservative estimate. The hemorrhages and spinal compressions in the smallest brook trout were small and difficult to see, and some might have been overlooked. It was difficult to detect class-1 and class-2 spinal injuries on the Blue Brand BB-1 film X rays because incorrect exposure or out-of-date film produced grainy, faded images with poor detail. Also, because we did not take dorsal X rays, horizontal dislocation of the spine was hard to detect. However, class-3 spinal injury was relatively easy to detect despite the poor image quality. Although the X-ray image quality of the Industrex film was excellent, that film was used on only 173 brook trout from Smays Run and 71 and 69 of the smaller brook trout from Little Fishing Creek and Galbraith Gap Run. The remaining 266 brook trout (46%) were X-rayed with Blue Brand film. Though the type of X-ray film may have influenced the apparent high rate of spinal injuries in the brook trout from Smays Run, these fish also had the highest incidence of hemorrhages (20%). This indicates that the high number of injuries was not a result of the X-ray film used but of some other aspect of that stream. Among the fish from Gann Run, Little Fishing Creek, and Galbraith Gap Run, the incidence of hemorrhages was 7, 9, and 14%, respectively.

The injury rate of brook trout from Smays Run was apparently much higher than that of fish from the other streams, but the reasons for this are un-

TABLE 6.—Hatchery studies documenting electrofishing injury to domestic trout. (N = total number of fish in sample.)

Species and average length (cm)	Stream conductivity (μS/cm)	Electrofisher variables: Current	Voltage	Frequency (Hz)	% fish mortality (N)	Study duration (d)	% fish with spinal injury (N)	Reference
Brook trout								
17	10	AC	350–760	250–300	0.5 (1,125)	15	3 (1,125)	Hudy (1985)
25	308	AC	110		5 (46)	18		Pratt (1954)
25	308	DC	230		0 (50)	18		Pratt (1954)
Brown trout								
20	308	AC	110		10 (38)	18		Pratt (1954)
20	308	DC	230		2 (48)	18		Pratt (1954)
Rainbow trout								
20	10	AC	350–760	250–300	2 (1,125)	15	2 (1,125)	Hudy (1985)
19	308	AC	110		2 (46)	18		Pratt (1954)
19	242	PDC[a]	45	60	2 (102)	35	39[b] (102)	Horak and Klein (1967)
20	(Alkaline)	DC	230		12 (16)	10		Bouck and Ball (1966)

[a] Pulsed DC.
[b] These fish had "burn marks" ascribed to internal bleeding and spinal fractures but were not X-rayed.

known. In Smays Run, 41% of electrofished brook trout were injured by AC and 41% by PDC, compared with averages of 21% injured by AC and 13% by PDC in the other streams. We cannot provide a reason for the significant difference in injury rate between Smays Run and the other streams. We chose these sites because of their similarity in size, water chemistry, and substrate. The obvious difference among streams was the unexpectedly high conductivity in Gann Run (Table 1), where the incidences of spinal injury and hemorrhage were lowest. Even when we omitted data from Gann Run, injury rate among the other streams was significantly different (χ^2, $P < 0.05$).

Many wild trout populations have a low background incidence of spinal injuries (detectable by X ray) resulting from congenital defects or previous physical injuries (e.g., Sharber and Carothers 1988). We found less than 7% of angled brook trout had spinal injuries, but the incidence varied from 0% in three streams to 12% in Gann Run. All study streams had been electrofished in the past, but Gann Run was shocked the most recently—July 1990. Although the angled brook trout from Gann Run may have been injured by electrofishing the previous year, their injuries were judged to be of more recent, but unknown, origin. Sharber and Carothers (1988) reported that 5% (N = 60) of wild rainbow trout they collected by electrofishing had fused vertebrae due to natural causes. Gill and Fisk (1965) reported that 2.8–3.3% (N = 19,557) of the three species of Pacific salmon taken in commercial catches and X-rayed had fused or compressed vertebrae. Fredenberg (1992) observed 0% spinal injury on X rays but 8% hemorrhage at autopsy (N = 85) in wild rainbow trout captured by nets or traps from three Montana waters. McCrimmon and Bidgood (1965) reported that about 8% (N = 291) of rainbow trout from four Great Lakes tributaries had fractured vertebrae. This was attributed to natural causes, although the rainbow trout were collected by electrofishing. Differences between recent and old injuries are often subtle, and distinguishing them is difficult. Although the absence of hemorrhage may sometimes be indicative of old injury, we found that spinal injuries often were not accompanied by hemorrhages.

With X rays, we detected 15% (N = 579) incidence of spinal injury to wild brook trout from streams, yet Hudy (1985) reported only 3% (N = 1,125) spinal injury in domestic brook trout exposed to AC and PDC electrofishing in hatchery raceways. Because he X-rayed only 4% of normal-appearing trout, some injuries could have been missed. Also, Sharber (1986) suggested that Hudy's combination of low conductivity (10 μS/cm) and small electrode surface area resulted in the low injury rate. It is also possible that domestic trout in hatcheries react differently to electrofishing than do wild trout in streams; thus, studies of domestic trout in hatcheries may not be applicable to wild trout under field conditions. We compared data on electrofishing spinal injury and mortality of domestic brook trout, brown trout, and rainbow trout in hatchery studies with results of similar studies of wild trout in streams. Exposure to AC and PDC electrofishing, on average, resulted in spinal injury in 4% (range, 2–39%; N = 2,352) of domestic trout (Table 6), compared with a mean

TABLE 7.—Field studies documenting electrofishing injury to wild trout. Mortality was not assessed in these studies.

Species and average length (cm)	Stream conductivity (µS/cm)	Electrofisher variables			Fish in sample			Reference
		Current[a]	Voltage	Frequency (Hz)	% with hemorrhage	% with spinal injury	N	
Brook trout								
14	43–440	AC	125–400	250–300	13	18	281	This study
14	43–440	PDC	200–500	60	13	13	298	This study
Brown trout								
40	300	DC	400			10	50	Fredenberg (1992)
39	300	PDC	400	60		53	100	Fredenberg (1992)
36	299–605	PDC	280–?	60		84	45	Meyer and Miller (1990)
Rainbow trout								
34	299–605	PDC	280–?	60		69	59	Meyer and Miller (1990)
38	177–540	DC	200–400		31	24	159	Fredenberg (1992)
38	44–890	PDC	125–400	60	71	47	257	Fredenberg (1992)
(1.7 kg)	(alkaline)	AC	80–90	60	20	60	10	Hauck (1949)
36	600–800	PDC	260	60		50	209	Sharber and Carothers (1988)

[a] PDC = Pulsed DC.

of 33% (range, 10–84%; N = 1,468) for wild trout in their natural environment (Table 7). Perhaps wild trout are stronger, and their contractions dislocate and fracture vertebrae more often than domestic trout; or it may be that domestic trout have more flexible bones due to their diet or genetics. However, to our knowledge, no studies that directly compared injury levels in domestic versus wild trout have been published.

The ultimate test of electrofishing effects is mortality. Evidence is lacking from field studies, but hatchery studies indicate 0.5–10% (N = 2,482) mortality within 15–35 d after AC or PDC electrofishing (Tables 6, 7). Mortality of wild trout under natural conditions may be much higher than that estimated for domestic trout in hatchery studies. Relatively stable temperatures, flows, food supply, and electrofishing fields under hatchery conditions may not realistically represent the more rigorous natural conditions and fluctuating electrical currents (caused by changes in generator loading, water depth, substrate conductivity, and physical obstructions to the electrical field) encountered by wild fish. No one has specifically addressed the long-term effects of repeated electrofishing on mortality of a wild trout population. A reduction in natural mortality might compensate for electrofishing injury and mortality. Thus, further study of the relationships among electrofishing, the well-being of injured wild trout, and the consequences to their populations is needed.

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